Development of REBCO Coated Conductors on Low Magnetic Textured Metal Substrates

Hajime Ota, Masaya Konishi, Yuki Shingai, Tatsuoki Nagaishi, Takahiro Taneda, Kazuya Ohmatsu
Sumitomo Electric Industries, Ltd. 1-1-3, Shimaya, Konohana-ku, Osaka, 554-0024 Japan

Abstract—**In the R&D of coated conductors, we had been using textured metal substrates with magnetism. For AC applications such as power cables, motors, superconducting magnetic energy storages (SMESs) and others, we had to reduce the magnetism of substrates. To reduce the magnetism of the substrate, we developed low magnetic clad-type substrates. Improvement of the surface morphology of the clad-type substrate led to the increase of Ic. We obtained the maximum Ic of 380 A/cm with $GdBa_2Cu_3O_y$ superconducting film of 2 μm thickness. We also improved the production rate of the buffer layers by increasing the line speed and the tape width. As a result, the average speed of 20 m/h was achieved without any degradation of substrate properties. The expansion of tape width from 1 cm to 3 cm was achieved keeping uniform across-the-width characteristics of buffer layers.**

I. INTRODUCTION

In the R&D of high-Tc superconducting (HTS) wires, $(Bi,Pb)_2Sr_2Ca_2Cu_3O_x$ (Bi2223) wire of up to 1 km long has already been developed [1]. Meanwhile, $REBa_2Cu_3O_y$ (RE123, RE = rare earth element) coated conductor with high critical current density (J_c), so-called second-generation HTS wire, has been also developed. We have been fabricating RE123 coated conductor with textured metal substrates [2]. In the past, we used Ni alloy as substrates. However, the Ni-alloy substrates had two crucial problems. One is the large hysteresis loss because of magnetism of Ni and another is the low mechanical strength. For AC applications such as power cables, motors, superconducting magnetic energy storage (SMESs) and others, we had to reduce the magnetism of substrates. Therefore, we developed low magnetic clad-type substrates. In addition, low cost is essential to replace conventional wires. To reduce the cost of coated conductors, we studied the improvement of production rate of buffer layers. In this paper, we report the development of coated conductors on clad-type substrates and improvement of production rate of the buffer layers.

II. EXPERIMENTAL

The architecture of the coated conductor is superconducting layer / buffer layers / metal substrate. We employed clad-type substrates for the metal substrates. Buffer layers consist of CeO_2, YSZ, and CeO_2. All buffer layers were grown by a reel-to-reel (RTR) RF sputtering method. The first CeO_2 layer on the metal substrate is the seed layer. The second YSZ layer is the diffusion barrier. The top CeO_2 layer is the lattice-matching layer between the superconducting layer and the YSZ layer. The thickness of each layer was 150 nm, 260 nm, and 70 nm, respectively. The superconducting layers are $GdBa_2Cu_3O_y$ (Gd-123). Three or more superconducting layers were deposited by RTR pulsed laser deposition system to achieve high Ic. The thickness of each layer was about 0.3 to 0.5 μm. Crystal orientation was characterized by X-ray diffraction (XRD, θ-2θ and the pole-figure measurements). Surface morphologies and surface roughness were investigated by scanning electron microscope (SEM) and atomic force microscope (AFM).

III. RESULT S AND DISCUSSION

A. Magnetic and Mechanical Properties of the clad-type substrate

To confirm improvements of the magnetism and the mechanical strength by using the clad-type substrate, we measured these at 77K. Table I summarizes the comparison of the hysteresis loss and the mechanical strength of a Ni-alloy substrate, a clad type substrate and hastelloy at 77K. Hysteresis loss and the mechanical strength of the clad type substrate were improved compared with those of the Ni-alloy substrate and were close to those of hastelloy. In the measurement of the hysteresis loss, the magnetic field was applied parallel to the surface of the substrate.

TABLE I
COMPARISON OF THE HYSTERESIS LOSS AND THE MECHANICAL STRENGTH OF A NI-ALLOY SUBSTRATE, A CLAD-TYPE SUBSTRATE AND HASTELLOY AT 77K.

Substrate	Hysteresis loss (J/m^3)	Strength (MPa)
Ni-alloy	1300	200
Clad-type	52	500
Hastelloy	~0	500-1,000

B. Improvement of the clad type substrate for high Ic

The Ic of superconducting layer on the clad-type substrate was lower than that on the Ni-alloy substrate. The maximum Ic with the thickness of 2.0 μm on the clad-type substrate and the Ni-alloy substrate were 210 A/cm and 350 A/cm, respectively. We compared the characteristics of the clad-type substrate to those of the Ni-alloy substrate and found that the surface roughness of the clad type substrate was larger than that of the Ni-alloy substrate. We identified that the surface roughness was the cause of the low Ic. To improve the surface roughness of a clad-type substrate, we introduced a polishing process. As a result, the surface roughness (Ra) was improved from 50 nm to 30 nm. In addition, the Ic on the polished clad-type substrate was improved to the same level of Ic on Ni-alloy substrate. The maximum Ic with 2 μm thick superconducting layer was 380 A/cm. Fig. 1 shows the thickness dependence of the Ic.

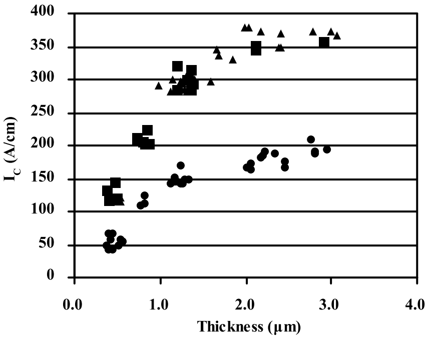

Fig. 1. Thickness dependence of Ic on Ni-alloy substrate (■), clad type substrate with polishing (▲), and clad-type substrate without polishing (●).

C. Improvement of production rate of buffer layers

Deposition parameters such as line speed, tape width and deposition area are related to the production rate of buffer layers by RTR RF sputtering system. We tried to increase the line speed and tape width for high production rate.

1) Increasing the line speed: The standard line speed of the seed-CeO_2 layer, the YSZ layer, and the cap-CeO_2 layer were 7 m/h, 3.5 m/h, and 12.5 m/h, respectively. The target line speed was set 20 m/h for all the buffer layers. However, the deposition time decreases with increasing the line speed. Consequently, thickness of each buffer layers became thinner than that at standard the line speed. Buffer layers have the function of controlling the inter-diffusion of substrate atoms. So, we studied the improvement of production speed by keeping the thickness of buffer layers and increasing the deposition rate. To increase the deposition rate, we increased the RF power, reduced the deposition gas pressure and expanded the deposition area along the longitudinal direction. As a result, an average speed of 20 m/h was achieved without degradation of characteristics of the buffer layers (Ra = 20nm, $\Delta\Phi$ = ~6deg.). Fig. 2 shows the line speed dependence of $\Delta\Phi$.

2) Expansion of the tape width: We tried to expand the tape width from 1 cm to 3 cm. We fabricated buffer layers on 3 cm wide substrate and investigated the distribution of across-the-width characteristics. Fig. 3 shows the distribution of $\Delta\Phi$ in the width direction. At all buffer layers, the distribution of $\Delta\Phi$ was uniform and similar to those of 1 cm width tape. Furthermore, the tape was slit from 1 cm to 3 cm after depositing the buffer layers on 3 cm width substrate, after which the superconducting layers were deposited. Ics of the three parts with 0.4 μm thick superconducting layer were about 100 A/cm. As described above, the tape width of 3 cm was achieved keeping uniform distribution of across-the-width characteristics.

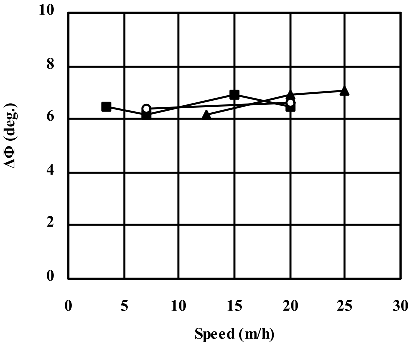

Fig. 2. Line speed dependence of ΔΦ ((○) seed-CeO_2 layer, (■) YSZ layer, (▲) cap-CeO_2 layer).

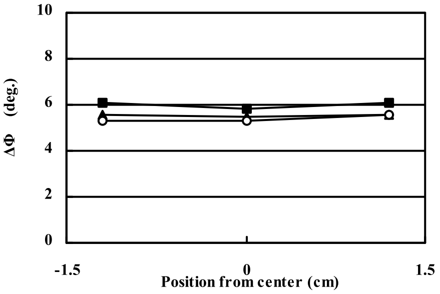

Fig. 3. Distribution dependence of ΔΦ ((○) seed-CeO_2 layer, (■) YSZ layer, (▲) cap-CeO_2 layer).

ACKNOWLEDGMENT

A part of this work was supported by the New Energy and Industrial Technology Development Organization (NEDO).

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